

Acoustic simulation of Elizabeth I at Tilbury

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Abstract

The largest gatherings in human history prior to the advent of electronic amplification were all effectively limited by the loudness and intelligibility of the human voice. Various accounts throughout history depict single orators addressing crowds or armies of many tens of thousands, though some historians have cast doubts onto the veracity of these claims. Prior acoustic simulation has shown that reasonable intelligibility might be achieved for over 20,000 listeners for very loud orators and very quiet crowds with high density. Nearly all such accounts, however, depict a man addressing the crowd, with one notable exception: in 1588 Elizabeth I of England addressed a large army of between 5,000-23,000 troops gathered to repel the impending invasion by the Spanish Armada. The acoustic plausibility of this account is tested via STI simulations, focusing primarily on the density, noise, and environmental conditions at the time of the speech, as well as the frequency-dependent differences between female and male orators' vocal spectra and a sound radiation patterns.

Keywords: Acoustics, Intelligibility, Elizabeth I, Spanish Armada, Oratory

1 INTRODUCTION

Before the advent of electronic amplification, the largest gatherings in history were effectively limited by the maximum intelligible range of a single human voice. Many accounts throughout history depict a single commander addressing their troops, and modern plays and films often show an army drawn up for battle receiving inspiration from a charismatic general with a voice loud enough to reach every soldier.

Until the 1990s, modern historiography largely accepted these accounts throughout history, primarily on account of the many references by different ancient writers. However, in 1993 Mogens Herman Hansen questioned the very existence of the general's speech to the army, arguing that the inclusion in ancient histories was largely rhetorical, meant to advance the argument of the speech attributed to the general [20]. The next year W. Kendrick Pritchett responded with the traditionalist position, showing many other accounts throughout ancient and modern history, including many where speeches were reported though no words were recorded [31]. Interestingly, both the skeptic (Hansen) and the traditionalist (Pritchett) both made allusions to acoustics in their essays, although neither made any detailed quantitative or perceptual argument.

Acoustical analysis, however, was attempted centuries earlier by Benjamin Franklin as he attempted to verify the very large crowd sizes reported in England listening to the Reverend George Whitefield in 1739. Franklin used Whitefield's on-axis intelligible distance to estimate the area of a semicircle and the number of listeners that could fit inside this space [17]. Analysis [8] and computer simulation [6] of Franklin's experiment show that Whitefield must have had a very loud voice, with an on-axis A-weighted time-averaged SPL of around 90 dB; this is similar to the largest dB values recorded for trained vocalists in laboratory conditions in the existing literature [9]. This in turn is roughly 12-16 dB over the relevant standards for loud speech in the general population [1]. Previous simulations have predicted that Whitefield (assuming overall vocal level of about 90 dBA) could be heard intelligibly by over 20,000 listeners even assuming moderate noise and density conditions [6].

However, for different historical situations the maximum crowd size may vary drastically due to other factors. Computer simulations of Julius Caesar's post-battle speech after his loss at Dyrrachium have shown that the historical account is acoustically plausible even under pessimistic conditions. But for Caesar's pre-battle speech at Pharsalus, due to the noise of soldiers on the march and the low density of his army in formation, even under optimistic noise conditions it does not seem acoustically plausible that Caesar could have addressed his

entire army as described [7].

Other such famous speeches throughout history are much treasured by their respective cultural descendants though often called into question by historians. Because nearly all participants in ancient warfare were men, so too nearly all speeches to large audiences are recorded with male generals or kings addressing the troops. One significant outlier to this pattern is England's Queen Elizabeth I (1533-1603, r. 1558-1603) who gave many public speeches after gaining the crown. The largest crowd attributed to Elizabeth (and perhaps the largest crowd addressed by a woman in pre-amplified history) was the army she had gathered at Tilbury to prepare for the invasion by the Spanish Armada in 1588.

This paper will first give some background on Elizabeth's rhetorical training and physical stature, as well as the historical estimates for the size of her army at the time she visited Tilbury. Next, the speech's intelligible range is investigated via geometrical acoustic simulation. Finally, some conclusions are drawn about Elizabeth's maximum intelligible crowd size as well as the effects of the female spectrum when addressing large outdoor crowds.

2 BACKGROUND

2.1 Education and Experience

The daughter of Henry VIII and Anne Boleyn, Elizabeth's mother was charged with treason and beheaded in 1536 when the child was only three years of age. The marriage was annulled, making Elizabeth an illegitimate heir of the king. However, Henry did ensure that his daughter would receive the education of "a Renaissance Prince" [35]. Her main tutor, the Cambridge scholar Roger Ascham, claimed that "no six of the best gentlemen of this court" could equal his student in diligence or learning [33]. The humanist education she received privileged the classical Greek and Roman models of language and rhetoric, and Elizabeth learned to read and converse in six languages besides English [35]. In particular Elizabeth studied the oratory of both Demosthenes [33] and Cicero [4], perhaps with some forethought given to her possible future on the throne, given that her father restored her to the line of succession before his death in 1546 [35]. As Mary Thomas Crane put it, "Elizabeth was trained, as other women were not, in the use of rhetoric to assert authority." [12]

Indeed, Elizabeth frequently used her reputation for scholarly and rhetorical excellence to justify the then-controversial idea of an unmarried female monarch in England [33]. Before her coronation, Elizabeth gave a speech to a large outdoor crowd in London in 1559, and later gave pre-written speeches to Parliament establishing her own authority to choose when and whether to marry [4]. In addition, she gave addresses in Latin in 1564 at Cambridge University to a crowd estimated at 1,800, and another in 1566 at Oxford University, to a crowd estimated at 1,700 [32]. But her most famous speech, for various reasons, is undoubtedly her Tilbury address of August 19th (August 9th Old Style), 1588, to her army awaiting the invasion of the Spanish Armada. Given her exceptional rhetorical training and experience in public speaking, Elizabeth's effective vocal level (including benefits from superior elocution, which are not included directly in an STI simulation but will affect intelligibility and so can be included by increasing the vocal SPL instead) was probably higher than for the average speaker. However, the second variable correlated with very high vocal levels is youth [24], and since Elizabeth was in her mid-fifties at the time of the Tilbury speech, she probably could not attain the exceptionally high vocal levels (around 90 dBA) associated with the loudest human speech [9]. Because of this, Elizabeth's overall vocal level at 1 m is assumed here to be 80 dBA, applying the IEC standard female spectrum [2].

2.2 Occasion and Audience

The fortress at Tilbury, first built under Henry VIII, was located at the mouth of the Thames River and provided a defense against an invading force headed for London. As it became clear that the Spanish intended to invade, Elizabeth charged the Earl of Leicester with heading the Royal Camp at Tilbury and ordered her troops to gather there to prepare for an attack on London. By the time Elizabeth decided to visit her troops at Tilbury on August 18, the English fleet had already defeated the Armada at sea. On land the extent of the damage to

the Armada was still largely unknown, and an invasion by the Spanish army, led by the Duke of Parma, was still expected [28].

At Leicester's invitation, Elizabeth and her guard took barges from London to Tilbury and inspected the troops on August 18th, carrying a truncheon but wearing no helmet. She stayed nearby that evening, and returned to the camp the next day, where she gave her famous speech:

I know I have the body of a weak and feeble woman, but I have the heart and stomach of a king, and of a king of England too, and think it foul scorn that Parma or Spain, or any prince of Europe, should dare invade the borders of my realm; to which, rather than any dishonour shall grow by me, I myself will take up arms, I myself will be your general, judge, and rewarder of every one of your virtues. [35]

Due to the haphazard nature of the English response to the Armada, precise numbers are lacking for the English forces. Elizabeth planned to assemble over 100,000 men to repel the invasion [10], and early Elizabethan chronicler William Camden reported the forces at Tilbury at 23,000 [28].

Some historians have expressed skepticism toward this value: Parker [30] gives the lowest estimate of only 5,000 based on pay records for the Kentish forces, while Frye [18] guesses 8,000 based on Leicester's personal correspondence. However, even these low estimates need to add Elizabeth's own guards and retinue, which filled several barges and must have numbered at least in the hundreds [10]. Hutchinson [22] puts the number at 16,000 infantry and 2,000 horsemen, while Christy [10], relying on the chronicle of Elizabeth's Privy Council, puts the number at 18,000 footmen and 2,000 horsemen, plus additional troops south of the river at Gravesend. Mattingly [28] argues for a value in between the high and low estimates, without giving a specific guess.

As important as the size of the army is the layout and density of the troops hearing the speech. Previous work has shown that the largest intelligible area is present for informal speeches where the crowd encloses the speaker densely on all sides [6, 7]. Though we do not have perfect documentary evidence for the layout of Elizabeth's army, the descriptions of the event suggest a more formal affair. It is true that the occasion of the Queen's visit provoked ecstatic and even worshipful bows from her troops when she arrived on the 18th, which had to be stopped at the Queen's request [22]. However, the primary source descriptions of the event focus on her inspecting the army in formation, riding around the entire army on horseback with the rest of the mounted cavalry [10]. Thomas Deloney's 1588 account describes the atmosphere before her speech as follows (emphasis added):

The valiant Capitaines of the field,
meane space them selues in order set:
And each of them with speare and shéelde,
to ioyne in battaile did not let.

...

Such a battaile pitcht in England,
many a day hath not béene séene:

Thus they stood in order waiting,
for the presence of our Quéene.

At length her grace most royally,
receiued was and brought againe:

Where she might sé most loyally,
this noble hoast and warlike traine.

How they cam martching all together,

like a wood in winters weather.

With the strokes of drummers sounding,
and with trampling horses than:

The earth and aire did sound like thunder,
to the eares of euerie man.

The warlike Armie then stood still,
and drummers left their dubbing sound:

Because it was our Princes will,
to ride about the Armie round.

Her Ladies she did leaue behind her,
and her Guardes which still did minde her.

...

And then bespake our noble Queene. [15]

2.3 Setting

Though earlier historians had located the camp farther to the west at Purfleet, Christy's survey of the land, primary sources, and local tradition led him to the now-accepted conclusion that the camp was located on the

hill at what is today the village of West Tilbury [10]. This hill is more like a plateau, with a large flat plain to the north on which the army was encamped, with a steep drop-off to the south allowing a good view of the marshlands and the river. The queen and her guard rode up the hill to meet the army, and the speech was given on the plateau, so the overall geometry of the speech site was completely flat.

Hutchinson [22] estimates the size of the tented encampment at 5 acres (about 20,000 m²), but the plateau itself is much larger, containing over 2 square kilometers of flat ground to the north of the steep hills at the southern edge of the camp. The army seems to have had plenty of open space for the proceedings once Elizabeth arrived, as the entire force paraded past her and staged a mock engagement for her viewing. This suggests that the entire force was gathered together in one open area of the plateau, except perhaps the forces stationed at Gravesend south of the river.

Most historians have accepted Elizabeth's Tilbury address as authentic. The overall speech as recorded by Lionel Sharpe, one of Leicester's chaplains, is brief, about 250 words overall and has many rhetorical similarities to others of Elizabeth's published speeches [19]. One version of Sharpe's written account is subtitled "Gathered by on who heard it, and was commanded to utter it to the whole army the next day," [19], leading some to question how many soldiers could have heard Elizabeth's oration [35, 29].

2.4 Environment

Since any acoustical simulation must also account for the environmental background to properly simulate air absorption. Unfortunately, the well-known HadCET database of surface temperatures in Central England does not have data prior to 1659 [26]. Previous climate work has analyzed the famous "Protestant Wind" that stymied the Spanish fleet, including the relevant high and low pressure systems, but this did not include estimates of temperatures [16]. Period accounts suggest that the year 1588 was unusually rainy [3], although none of the accounts of Elizabeth's speech at Tilbury mention rain. Because of the "Little Ice Age" that was present in Europe during this period, the temperature might be expected to be slightly lower than modern averages, but since the accounts do not describe the weather as particularly hot or cold, it did not likely stray from normal values for early August. As a result, a value of 16.0° C, similar to long-term averages for Tilbury during August in recent years, was adopted for the acoustic models described.

Similarly, no historical data for percent humidity is available for the site of the speech, so an average value of 65% was adopted based on averages from recent years. Since August is a relatively humid time of the year, even the large uncertainty around this value may be of negligible significance in the final simulation, as sound absorption from air peaks below 20% humidity and is relatively small for all values above 50% humidity [21]. The final important acoustical question is the level of background noise in the army. Elizabeth's visit seems to have encouraged frequent outcries among the soldiers, as well as drums that were used while she paraded around the forces and significant noise from horses' hooves on the march [15] However, Deloney's account seems to emphasize the contrast of this noisy scene with the troops' awe and respect for their monarch when at last she spoke. At this point the cavalry was still and the drums were silenced, which may have given an implicit signal to the infantry in formation to be silent as well. While no doubt some foot soldier or horse may have made some small noise, overall the army seems to have been fairly quiet during the speech itself. As such, the army here is modeled with background noise values from 45 dBA (very quiet) to 50 dBA (quiet).

3 SIMULATION

3.1 CATT Model

Based on the historical data described above, Elizabeth's speech at Tilbury was simulated in CATT Acoustic v9.1 [14, 13], a popular cone-tracing acoustic simulation engine. The infantry was modeled as a flat square audience plane measuring 130x130m with a height of 1.5 m, corresponding to the largest estimation of about 20,000 troops at a density of 1.17 persons per m². In front of this was a 130x4 m empty grass space, corresponding to an assumed distance of 4 m between the infantry and cavalry. The cavalry was modeled as a

130x30 m plane with a height of 2.5 m (Figure 1). Elizabeth was modeled as a point source with human voice directivity in the center of the grass area and height 2.5 m, facing the infantry. Again, the exact height of Elizabeth's horse is not known, but previous analysis has shown that small changes in height do not significantly affect intelligible area, once a direct line of sight is established to every part of the crowd [5]. Elizabeth's voice was modeled with a standard IEC female spectrum with overall sound pressure of 80 dBA [2].

Absorption coefficients for the army and grass area are given in Table 1. Due to the nature of Sabine absorption coefficients, some high-frequency values were initially measured as greater than 1 but were truncated to 99% absorptive as that is the highest absorption value CATT allows [13]. Scattering coefficients were estimated using CATT's Lambert estimation function for an average surface roughness of 0.1 m for the army and 0.03 m for the grass.

Table 1. Absorption coefficients by octave band center frequency (Hz) for soldiers and grass in Tilbury model.

Surface	125	250	500	1000	2000	4000
Audience (1.17 persons per m ²) [27]	0.20	0.35	0.70	0.99	0.99	0.99
1.2" Dry Grass [25]	0.40	0.51	0.63	0.74	0.90	0.95

The army's background noise was modeled for a "very quiet" and "quiet" condition, corresponding to 45 dBA and 50 dBA respectively. The noise levels by octave band are given in Table 2.

Table 2. Background noise levels by octave band for different noise conditions modeled.

Surface	125	250	500	1000	2000	4000
45 dBA (very quiet)	55	48	41	36	33	31
50 dBA (quiet)	60	53	46	41	38	36

STI was simulated for the scene under both background noise conditions using the IEC STI (female) protocol [2]. The STI maps, with 2x2 m grid spacing, for both models are shown in Figure 1. It can be seen that the STI rating drops significantly over the 5 dB increase in noise conditions.

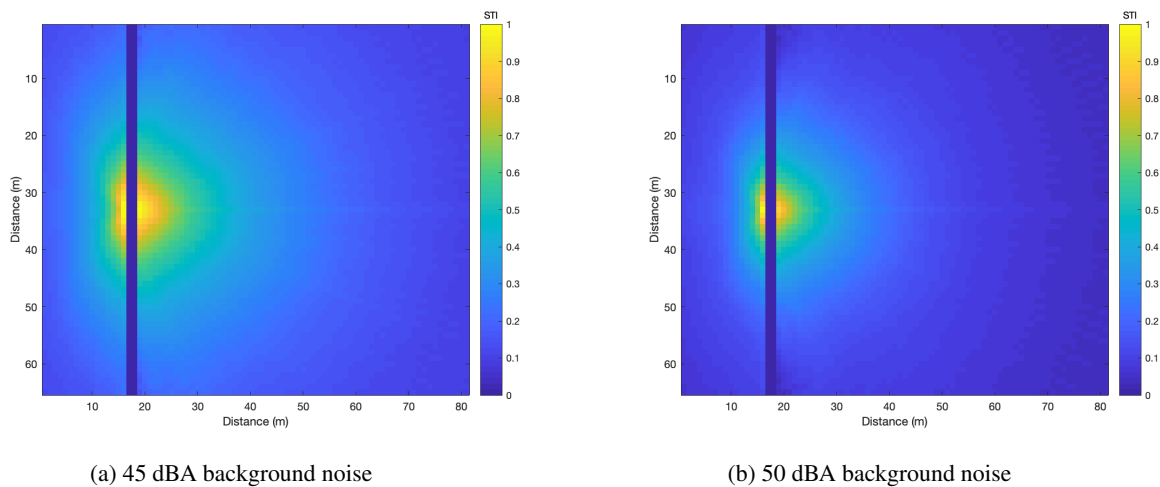


Figure 1. STI (0-1) at Tilbury Based on Crowd Background Noise

3.2 Crowd Estimation

To estimate the size of the crowd that could have heard Elizabeth, the STI maps for both the infantry and cavalry were exported as text files representing a series of 2x2 m squares. These were read into a script in Matlab that summed the area for each group that was greater than a minimum STI threshold. In this study, as with previous work [6, 7], a threshold value of 0.3 for the STI was used, as this is usually seen as the value below which STI is “Bad” and also because perceptual phoneme-group scores drop significantly below this level [34].

The infantry’s density was assumed to be 1.17 persons per m², similar to that of other infantries in formation [23]. The cavalry was assumed to have a much lower density of 0.5 persons per m², though the exact size of horses in Elizabeth’s cavalry is not known to the author. Based on this data, estimations of the number of infantry and cavalry members who could have heard the speech were summed and shown in Table 3.

Table 3. Intelligible Crowd Sizes at Tilbury for Different Noise Conditions.

Noise Level	Infantry	Cavalry	Total
45 dBA	588	4975	5563
50 dBA	172	1732	1904

4 CONCLUSIONS

Based on the simulations shown here, it does not seem plausible for Elizabeth to have spoken intelligibly to an army of 20,000 at once, even assuming relatively optimistic conditions for the density of an army in formation, the distance between the infantry and cavalry, and the background noise of the assembly. While there is not sufficient historical evidence to prove the army did not crowd together into a denser configuration, all the subjective descriptions of the event seem to argue against it and for a more standard, spaced-out infantry formation. This computer model predicts that Elizabeth might have been able to be heard by 5,000 to 6,000 troops when they were extremely silent, which is in keeping with the smallest estimates for her force at Tilbury. If however, the larger force estimates are correct, it seems likely that a large portion (perhaps the majority) of her troops could not have made out the words of her speech, which supports the hypothesis that Sharpe wrote it down to deliver to the “whole army” the next day because many of them could not hear it the first time.

In the view of many of her royal councilors, Elizabeth was a woman in a man’s job, a job that included speeches to armies and parliaments. She often made reference to this fact and did so in the text of the Tilbury speech, claiming that she had “body of a weak and feeble woman, but ... the heart and stomach of a king.” [35]. In this case however, having the vocal tract of a woman may have helped her: although there is not significant difference in vocal radiation patterns between men and women [11], women’s smaller vocal tracts tend to increase the resonance at the higher frequency bands which are most important for speech intelligibility and are thus weighted most in the STI calculation [34]. While these frequencies are also more prone to air absorption, this effect is still relatively small over the distances in question. Because of this, in laboratory tests, trained women vocalists can often produce the greatest A-weighted speech levels even when male vocalists (who have larger vocal tracts and can produce greater subglottal pressure) produced greater flat-spectrum (Z-weighted) SPLs [9].

This suggests that, given equal oratorical training and opportunity, women would have been a better conduit for speeches to large audiences than men in terms of intelligible range. Unfortunately, in the historical record such occasions are hard to find: the author has searched extensively for large addresses by other female leaders like Joan of Arc or Cleopatra, but so far has not found evidence of anything on the scale of the Tilbury oration (tips from interested historians are always welcomed, of course). In this sense the Tilbury speech must be seen as one of those rarest occurrences in history: thousands and thousands of men – all intently listening to a woman.

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